

Research Article

Impact of sediment load on *Cyperus papyrus* growth in Lake Tana buffer zone, Northwest Ethiopia

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Abstract

Cyperus papyrus is the cornerstone of Lake Tana's buffer zone, a vital ecosystem supplying the Blue Nile. However, this critical area is under siege from excessive sediment runoff, primarily due to deforestation and unsustainable agricultural practices in the surrounding watershed. The lack of research on papyrus's response to varying sediment levels has hindered restoration efforts. To address this knowledge gap, a study was conducted between May and October 2020 near Lake Tana. Twelve experimental wetlands were constructed, each divided into four sediment treatments: control (0 cm), low (1 cm), medium (5 cm), and high (10 cm). Papyrus growth parameters, including height, diameter, new shoot count, and above and below-ground biomass, were monitored every two weeks. Results unequivocally indicate that sediment load significantly impacts papyrus growth. Plants subjected to high sediment levels exhibited stunted growth, with reduced height, diameter, and new shoot production compared to those in lower sediment or control conditions. Biomass measurements also revealed a substantial decline in both above and belowground plant matter under high sediment stress. These findings highlight the urgent need for sediment management strategies to protect and restore the papyrus-dominated wetlands of Lake Tana.

Key words: Buffer zone, constructed wetland, growth performance, restoration, sediment load



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Introduction

Cyperus papyrus plays a vital role in ecological functioning and is harnessed for socio-economic purposes. From an ecological perspective, papyrus swamps trap sediments and pollutants entering water bodies (Terer et al. 2012). Conservation work is essential as the papyrus communities in the wetlands around Lake Tana are threatened with extinction (Gebremedhin et al. 2018). Effective management of *C. papyrus* and its ecosystem requires knowledge of how varied sediment depths impact local wetland ecology. Recent quantitative studies by Geremew et al. 2018 have shown that catchments with disturbed papyrus swamps resulted in sediment yield three times greater than those with pristine papyrus vegetation. Some of the dominant macrophyte species in the southern and eastern shore of

Lake Tana were listed in the studies of (Wondie 2018). Although *Cyperus papyrus* swamps are widely recognized for their outstanding ecological and economic importance, limited attention has been given to how increased sediment influx affects the growth, structure, and ecological functioning of *C. papyrus* in the Lake Tana sub-basin. In particular, the impacts of sediment accumulation on plant performance and wetland sustainability remain poorly understood.

Loss of wetlands among Ethiopian Rift Valley Lakes has been linked to human activities, such as clearance of vegetation for agriculture and overgrazing (Awulachew et al. 2007; Giweta and Worku 2019). Papyrus wetlands around Lake Tana are no exception. They have historically served as buffers by reducing the risk of eutrophication in open water, but their function has been dramatically reduced in recent years (Mengistu 2020). Human activities not only influence the nature of river flow and sediment movement, but they also affect the growth performance of *C. papyrus* (Mulatu et al. 2024). High sediment load can fill and destroy wetlands (Huang et al. 2022). Sedimentation affects the distribution of flora and fauna and the overall productivity of wetlands (Molinos and Donohue 2009). High sediment deposition is known to have a wide range of effects, particularly on papyrus communities (Molinos and Donohue 2009), burying seeds, seedlings, and adult plants to varying depths, and increasing stress on the plant's survival and growth performance (Aedasong et al. 2019). Excessive accumulation in wetlands causes hypoxia in the root zone and physical stress on aquatic plants. In *C. papyrus*, hypoxia is known to impact height, new shoot recruitment, stem density, and stem diameter (Geremew et al. 2018; Maithya et al. 2021). Photosynthesis rate, number of bundle sheath cells, chlorophyll-a fluorescence, total chlorophyll content, and chlorophyll-a/b ratio are also known to be impacted in other wetland macrophytes by sedimentation (Vickruck and Richards 2021). Shoot elongation, high shoot mass ratio, short and thick roots, low specific root length and shallow root systems are examples of morphological adaptations that have enabled some wetland plants to escape sedimentation by acquiring oxygen and light, or by diminishing root oxygen demand (Pan et al. 2014b). Sediment stress, as an emergent consequence of such disturbances, adversely impacts the growth dynamics and functional performance of *C. papyrus*, a keystone species in many tropical wetland systems, thereby undermining its ecological role and resilience within these habitats (Tamaki and Obeidi 2023).

Cyperus papyrus in Lake Tana is a vital resource under stress from mainly anthropogenic activities, especially intensive agricultural activities and deforestation. A few regional initiatives have been launched, and more are planned, to help narrow its decline and sustain its beneficial services to society and nature. Many knowledge gaps exist regarding Lake Tana papyrus wetlands, making it difficult to design the crucial interventions that are required at different stages of restoration. Understanding the impacts of siltation on the Lake Tana community will shed light on how papyrus populations, and Lake Tana wetlands more generally, cope with these environmental stresses and help guide conservation and restoration efforts. Data on sediment depth impacts in one growing season should spur additional research into the impacts of siltation over long periods of time, an important aspect of sustainable wetland management. Therefore, this study investigates the impact of varying sediment depths on the growth performance of *C. papyrus* using a controlled artificial wetland experiment designed to simulate sediment conditions in the Lake Tana buffer zone.

Material and methods

Experimental design

The experiment was conducted in constructed wetlands at Bahir Dar University Maritime Academy Lake Tana campus near the Lake (11°37'33.60"N, 37°20'54.20"E). The system consists of three treatment beds and one control with three replications each. The beds were constructed 1 m × 2 m with 50 cm depth using a geomembrane liner and filled with composite sediment up to a height of 0.3 m. This composite media was 20–30 mm in diameter, as recommended by the Madania et al. (2010), and fed with the same amount of lake water for three consecutive days before planting papyrus. The experimental plants were collected from a Legdiya littoral wetland 10–20 cm deep. Fragments of rhizomes not greater than 40 cm *C. papyrus* plants were selected according to Gikas and Tsihrantzis (2014) and taken from the natural habitat of Legdiya Wetland and transplanted into their respective constructed beds, each with a surface area of 2 m², at a density of 30 rhizomes / 2 m² (Fig. 1)

Following a one-month acclimation period, each bed was fed with water through pipes from Lake Tana with the same average flow rate (measured with a stopwatch). The beds were labeled randomly (Fig. 2). All beds were planted with an initial depth of 30 cm of sediment. The control beds received no additional sediment. Treatments beds received 1 cm, 5 cm, and 10 cm of additional sediment, respectively, after one month. During the 10-day acclimation period, water depth was kept at 5 cm to ensure the viability of the specimens. Water was then added every day to maintain a 20-cm water depth. In the natural environment of Lake Tana, high sediment levels corresponded



Papyrus growth in experimental wetlands at 1 week and 1,3,4, and 5 months.

Figure 1. The experimental constructed wetland system monitored over a five-month investigation period.

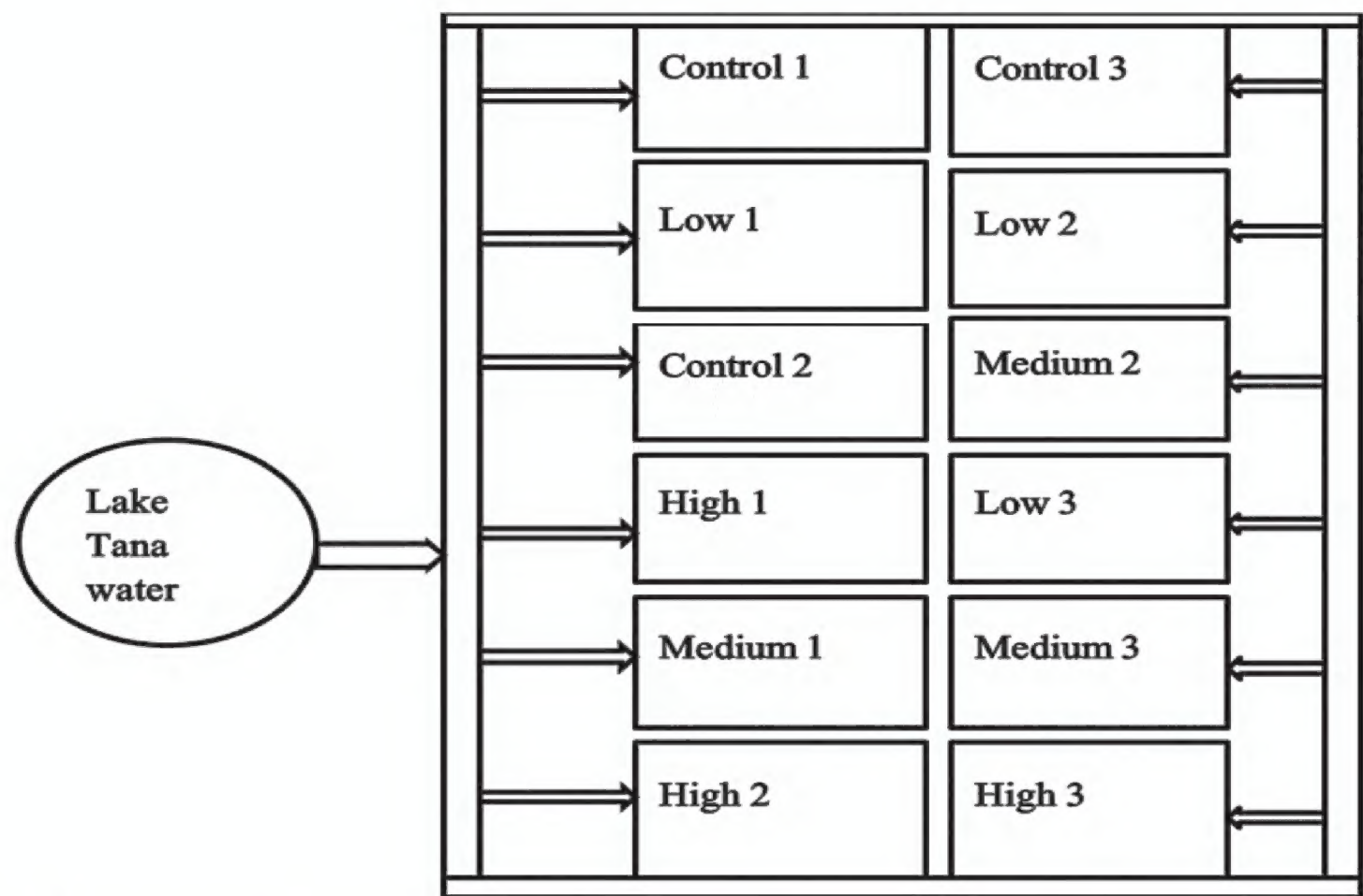


Figure 2. Simple diagram of experimental constructed wetlands, randomly assigned.

to the shallowest section (0.9 m sediment level) and a very low sediment regime represented a relatively deeper section of the lake (< 0.2 m sediment level) (Geremew et al. 2018). The climate conditions of the constructed wetlands were not controlled, such as with a greenhouse, in order to mimic the natural environment. The lake water, tested in the laboratory, produced average concentrations of SO_4^{2-} (0.89 mg/L), Zn (0.28 mg/L), Cr^{+6} (0.08 mg/L), Cu (0.28 mg/L), NO_3^- (0.19 mg/L) and NO_2^- (0.82 mg/L).

The experimental sediment was collected from Gilgel Abay at Chimba, Legdiya, and multiple other wetlands around Lake Tana, up to 10 km from Legdiya. The principal properties, measured once at the laboratory at the beginning of the experiment, are listed in Table 1.

Table 1. Properties of sediment used for the experiment.

	Sand (%)	Silt (%)	Clay (%)	Class	pH	K (Cmol+/kg)	TN (%)	TP (ppm)
Values	17	26	57	Clay	5.86	3.59	0.04	9.5

Data Collection from the Control Beds and Treatment Beds

Measurement of growth parameters

Ten individual culms were marked with a unique number (identification code) using a permanent marker. The length of each culm was measured above the rhizome from the end of the scale leaf to the apex of the umbel while the girth was measured just above the scale leaf according to (Muthuri and Jones 1997). All plant measurements were taken at two-week intervals from May to October, 2020 (Muthuri and Jones 1997; Opio et al. 2014). Measures included papyrus culm length and diameter. Papyrus height was measured from the ground to the top-most internodes of the shoot by use of a meter rule. Stem diameter was measured at the base of the stem (10 cm from the soil level) and below the flower using a Vernier caliper.

Recording papyrus culm density and new shoots

In each constructed wetland, individual papyrus culms were counted to get the culm density (i.e., total culms per unit area). New culm shoots were identified, recorded, and marked with a different number in each constructed wetland on every visit.

Data analysis

Prior to parametric tests, data was checked for conformity to normal distribution using the Shapiro-Wilk test using R and SPSS. The Kolmogorov-Smirnov test and Levene's test were used to evaluate normality and homogeneity of variance, respectively. Data that met the assumptions of normality and homogeneity of variance was analyzed using Analysis of Variance (ANOVA) for any significant differences in the measured variables among treatments beds and the control bed. Data that did not meet the assumptions were analyzed using the Kruskal-Wallis test. As most data were not normally distributed, the Kruskal-Wallis One Way non-parametric ANOVA (KW-ANOVA) was used to determine differences between sediment levels and papyrus growth parameters. This was followed by Kruskal-Wallis multiple comparison tests for post-hoc evaluation. Descriptive statistics were also used to analyze the growth parameters of *C. papyrus*. The relationship between population dynamics (culm density and new shoot density) and sediment depth in the constructed wetland was assessed using Spearman's rho rank correlation. To explore variations among treatments, a comparison of mean growth rate of papyrus was conducted. The relationship between culm height and diameter was determined by a linear regression analysis after data was log-transformed.

Results and discussion

Results

Growth characteristics of the plants

Papyrus height

Culm height growth was higher in papyrus with medium sediment, but lower in high sediment treatments (Fig. 3). Culm height was significantly smaller in the high sediment as compared to the low sediment treatment beds (KW-ANOVA, $df = 3$, $f = 4.3$, $P < 0.05$). Medium treatment beds also produced significantly greater culm height compared to the high sediment treatment bed (KW-ANOVA $f = 5.1$, $df = 3$, $P < 0.05$). There was no significant interaction between papyrus growth and sediment levels.

Stem diameter below the flower

Stem diameters in medium sediment beds were significantly larger than stems in the high and low sediment beds (KW-ANOVA, $f = 8.6$, $df = 3$, $P < 0.05$; Fig. 4). The mean stem diameter for medium sediment treatments (7.60 mm) was significantly higher than low (6.92 mm) and high treatments (5.04 mm) and the control (6.90 mm).

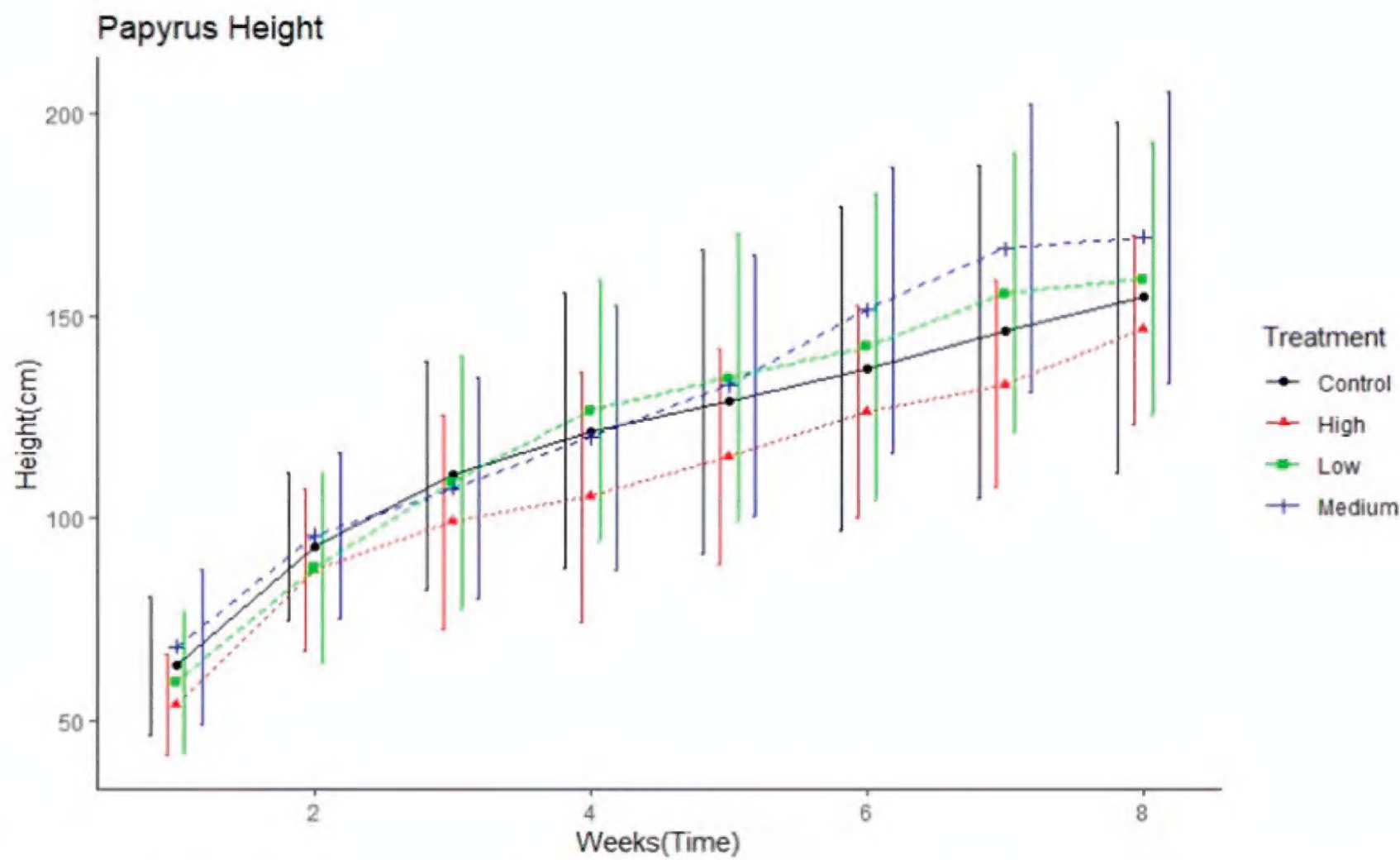


Figure 3. Height of *C. papyrus* (cm) grown at four sediment levels for eight weeks from June 2020 to October 2020 at two-week intervals.

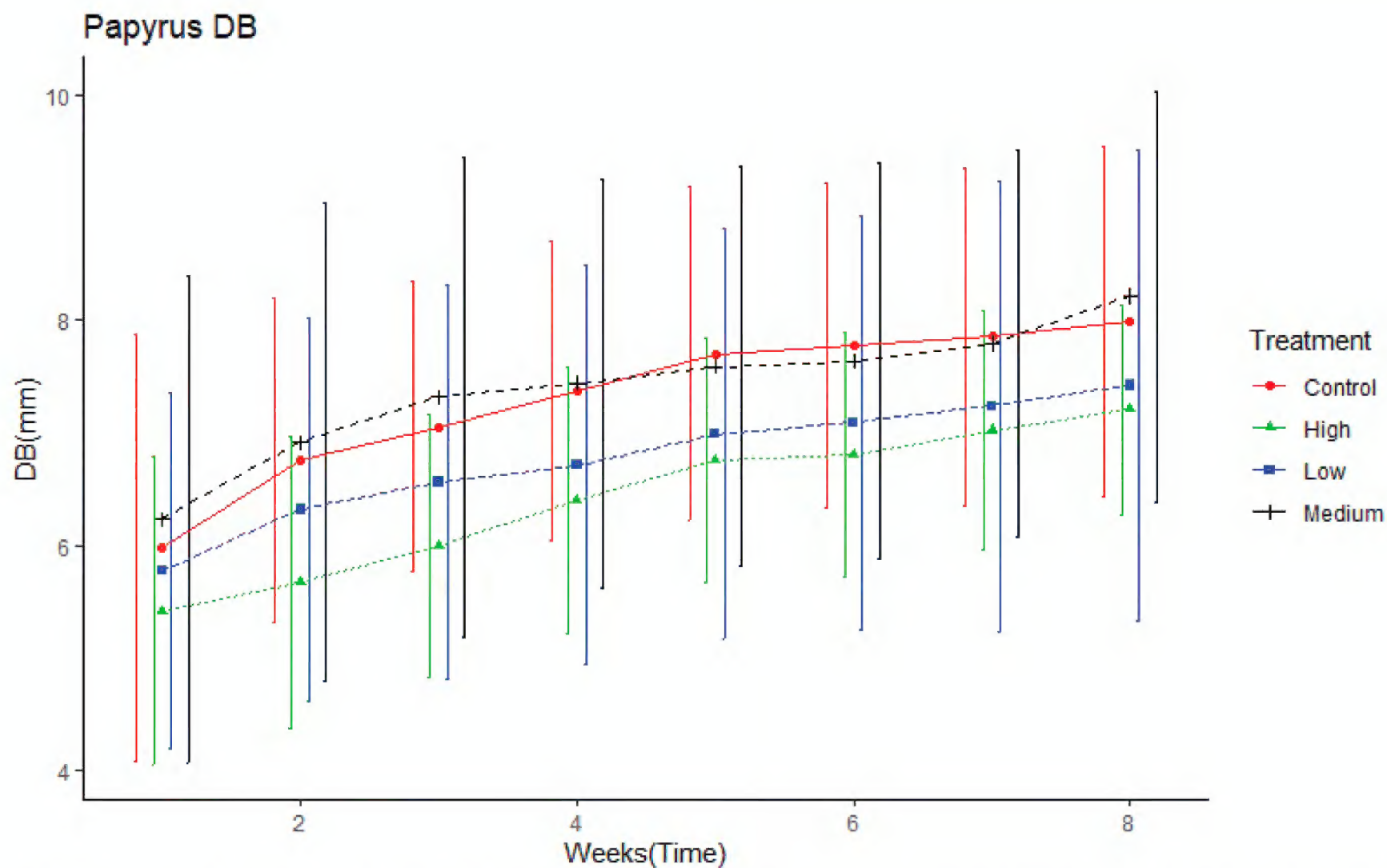


Figure 4. Stem diameter below the flower (DB) of *C. papyrus* (mm) grown at four sediment levels for eight weeks from June 2020 to October 2020 at two-week intervals.

Stem diameter above sediment

The stem diameters above the sediment in the medium sediment treatment beds were significantly larger than each of the other treatments and the control beds (KW-ANOVA $f = 9.6$, $df = 3$, $P < 0.05$). Stem diameters with medium

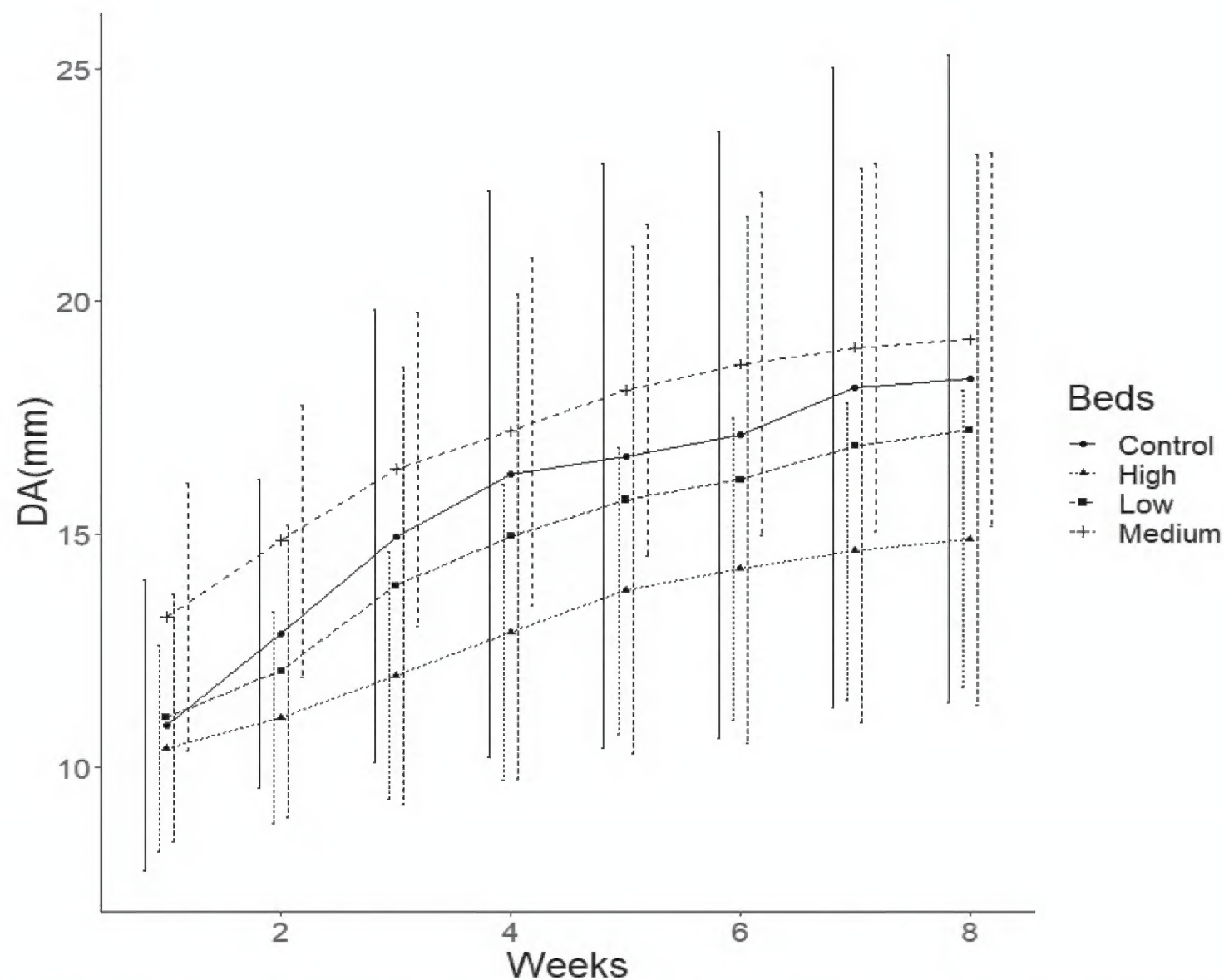


Figure 5. Stem diameter above the sediment growth (DA) of *C. papyrus* (mm) grown at four sediment levels for eight weeks from June 2020 to October 2020 at two-week intervals.

sediment steadily increased as compared to other treatments and control beds; plants in high sediment beds at the end of the experiment had smaller diameter stems compared to medium sediment beds (Fig. 5). The mean stem diameter for medium sediment beds was high (17.70 mm) compared to the low sediment (15.51 mm), high sediment (12.06 mm), and control beds (16.90 mm).

Density and new culm shoot recruitment

Papyrus culm densities differed among treatment beds and plants in control beds had the highest culm density (67 ± 23 culms/2 m²) as compared to the low (56 ± 21 culms/2 m²), medium (53 ± 20.5 culms/2 m²) and high treatment beds (35 ± 8.5 culms/2 m²). Kruskal-Wallis tests showed that there was a significant difference in papyrus culm density between control and low, medium, and high ($\chi^2 = 19.5$, $df = 2$, $P < 0.001$). One-way ANOVA and independent samples tests showed that there was significantly higher mean plant density between the control beds and the medium ($P < 0.001$) and high beds ($P < 0.002$; Fig. 6).

The recruitment of new culm shoots was highest in April in all the treatment beds with low treatment beds having the highest number (6.0 ± 2.0 culms/2 m²), followed by control beds (5.5 ± 1.6 culms/2 m²), and medium (3.8 ± 1.6 culms/2 m²) and high treatment beds (1.0 ± 1.5 culms/2 m²; Fig. 6). Notably, nutrient access is greater in April because of sediment additions at the start of the experiment. Culm density of new shoot recruits was lowest in the month of October in all the treatment beds, with control and low treatment beds having an average of one each while high treatment beds had 2.0 ± 0.3 culms/2 m². However, significant variations were not

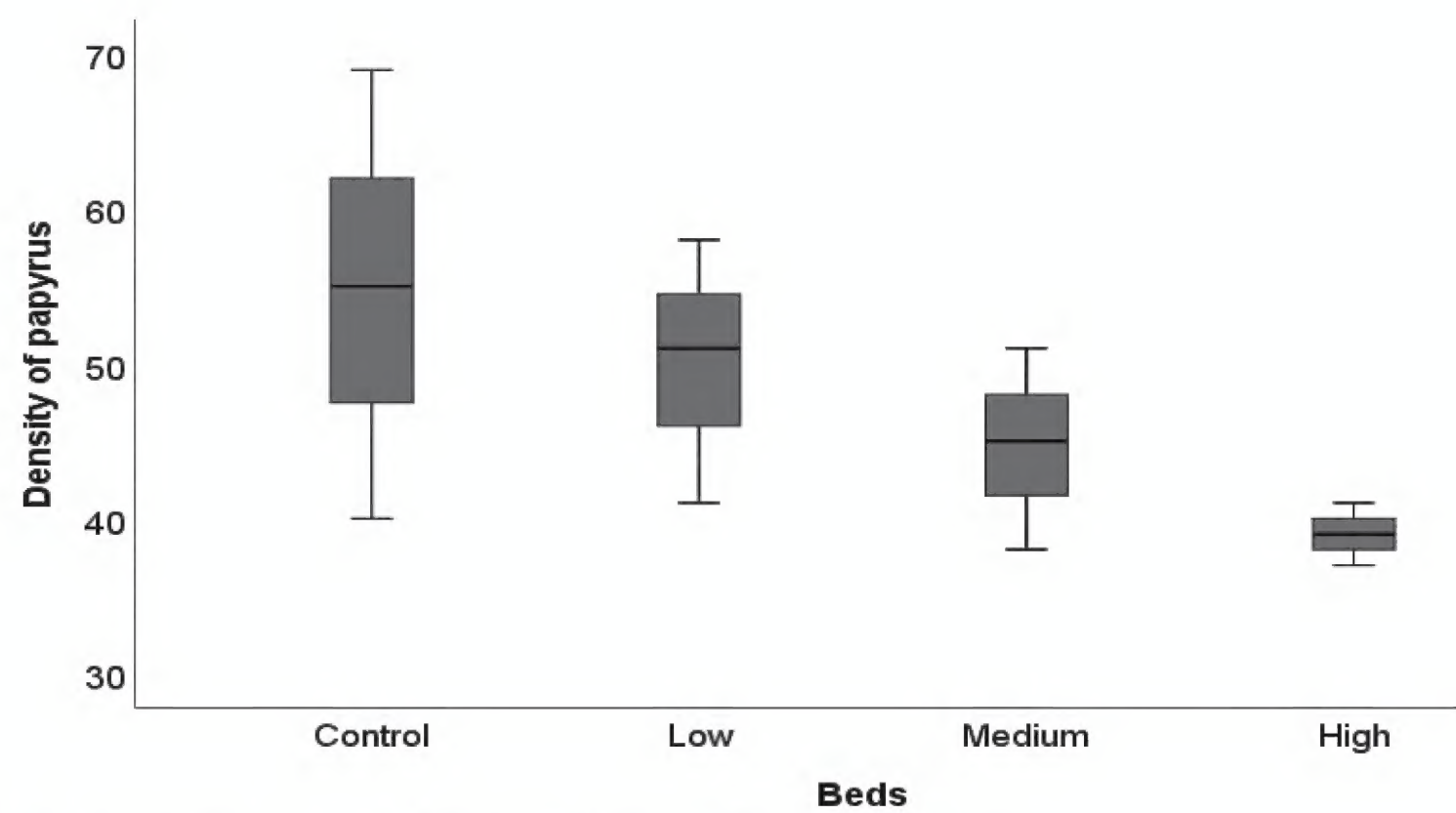


Figure 6. Culm density of *C. papyrus* in the control beds and treatment beds.

observed among treatment beds in October. The number of new papyrus’s shoot recruits was significantly affected by sediment depth ($P < 0.05$; Fig. 7). The number of new shoots decreased with 5 cm and 10 cm burial depths, and shallow burial depths (0 cm and 1 cm) usually had more new shoots than medium and high treatments.

Papyrus culm mortality was monitored throughout the study period. Senescing culms were observed to be higher in high sediment in the month of September at an average of 12.5 ± 4.5 culms/2 m² (KW-ANOVA, $\chi^2 = 8.24$; df = 2; $P < 0.05$). However, the high sediment treatment had the highest number of dead culms per 2 m². Furthermore, no difference in the number of dead culms was observed among and between treatments at the end of the experiment (October). According to Spearman’s coefficient of correlation,

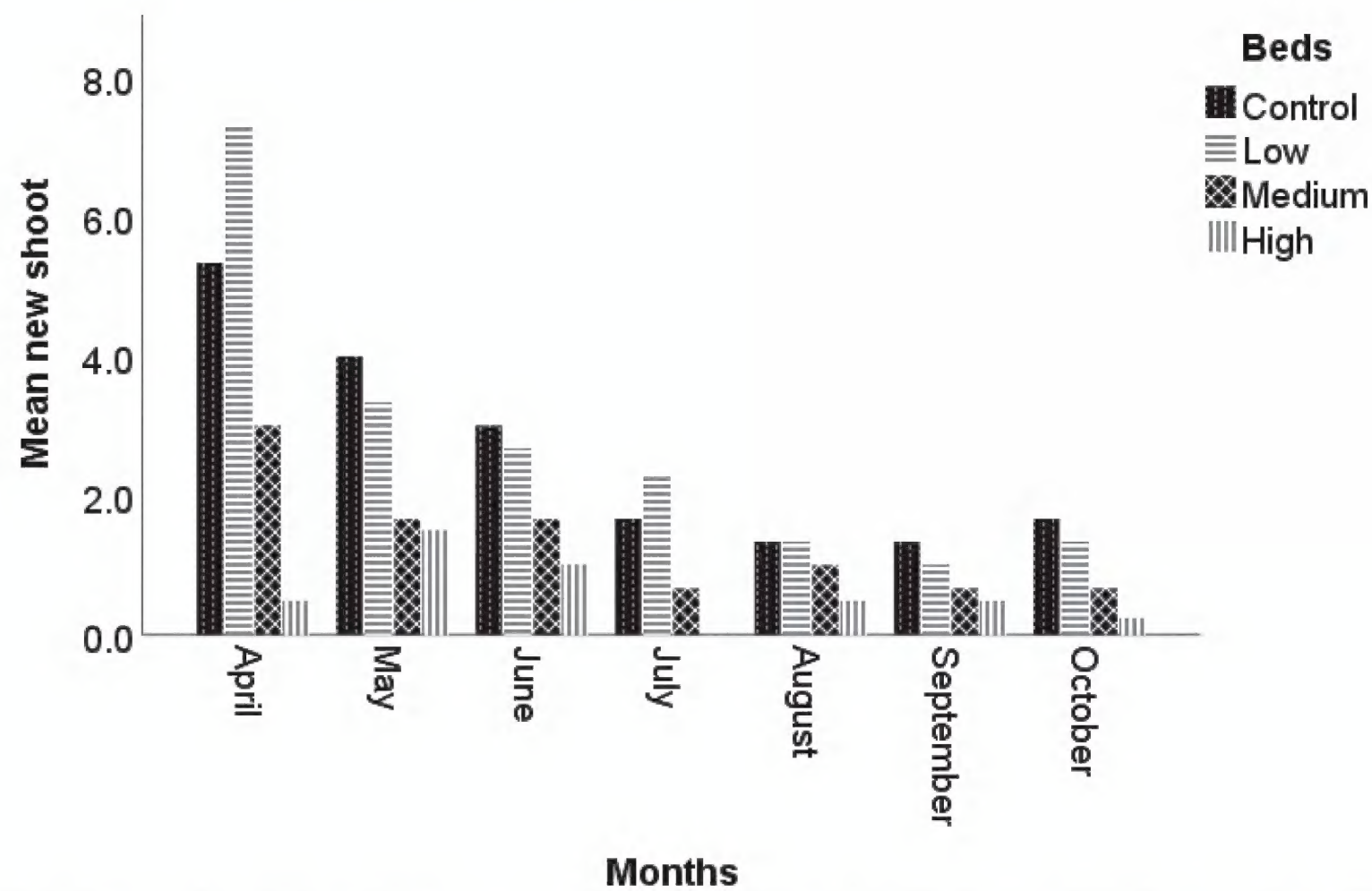


Figure 7. Recruitment of new shoots of *C. papyrus* at four levels of sediment from July to September 2020.

sediment depth did not have a significant influence on culm density and dying culms in all the treatment beds. However, sediment depth had a positive and significant relationship with the number of new shoot recruits in low ($\rho = 0.80$; $P = 0.01$) and control beds ($\rho = 0.80$; $P = 0.01$) but not in high ($\rho = 0.34$; $P > 0.05$) and medium beds ($\rho = 0.48$; $P > 0.05$).

Cyperus papyrus biomass productivity

Wet above-ground biomass

Sediment levels did not significantly affect wet above-ground biomass in control and low sediment treatment beds ($df = 3$, $P > 0.05$; Table 2) but it did significantly impact biomass in high and medium treatment beds ($df = 3$, $P < 0.05$). Control beds recorded the highest shoot wet weight with a mean of 3.33 kg compared to a low treatment mean of 3.10 kg, a medium mean of 3.00 kg, and a high mean of 1.93 kg.

Dry above- ground biomass

Dry above-ground biomass did not increase significantly ($df = 3$, $P > 0.05$) with increasing sediment depth (Table 2). The control beds recorded the highest mean shoot dry weight (2.76 kg/2 m²) compared with the low treatment beds (2.34 kg/2 m²), medium beds (2.01 kg/2 m²), and high beds (1.45 kg/2 m²).

Wet below-ground biomass

Root wet weights decreased with increasing sediment depth (Table 2). Plants in control beds had significantly higher root wet weight than high sediment treatment beds ($P < 0.05$, $N = 3$ and $df = 3$). The control beds had the highest mean root wet weight (7.16 kg/2 m²) compared to low treatment beds (6.26 kg/2 m²), medium beds (6.06 kg/2 m²), and high beds (3.80 kg/2 m²).

Dry below-ground biomass

Dry below-ground biomass decreased with increasing sediment depth among the treatment beds (Table 2). The control beds had the highest mean root dry weight (6.00 kg/2 m²) compared with the low treatment beds (5.08 kg/2 m²), medium beds (4.90 kg/2 m²), and high beds (3.21 kg/2 m²). There were no significant differences in root dry weights ($P > 0.05$) between the treatment beds.

Table 2. Mean biomass and ranges of production of *Cyperus papyrus*.

Beds	Biomass (kg/2 m ²)			
	Below-ground		Above-ground	
	Wet	Dry	Wet	Dry
Control	21.5 ± 7.1	15.1 ± 5.0	9.0 ± 3.0	13 ± 4.3
Low	18.2 ± 6.0	14.6 ± 3.8	8 ± 2.7	5.0 ± 1.7
Medium	17.8 ± 6.0	11.3 ± 4.9	7.3 ± 2.4	3.9 ± 1.3
High	7.9 ± 3.9	5.8 ± 2.9	3.7 ± 1.9	2.2 ± 1.1

Discussion

Plant height was significantly decreased by sediment depth (Fig. 3); this agrees well with the findings by Veeneklaas et al. (2011) working with the clonal structure of *Elytrigia atherica*. The higher densities and a slight increase in papyrus height in the control beds of the present experiment demonstrated that less sedimentation can lead to increased biomass. Previous studies by Chen et al. (2011) indicated a shift of resource allocation to shoots which enhance below-ground growth and productivity with increased sediment. Under deep burial conditions (> 5 cm), our observations were consistent with those of previous studies (Li et al. 2016) which found that papyrus cannot acclimatize to high sediment.

The stem diameter below the flower of plants in the medium sediment treatment (5 cm) steadily increased from 3 mm to 10 mm diameter and then stabilized between 10 mm and 17 mm. This increase may suggest an effect of sediment load. As the sediment load increases, the plants in the high sediment treatment are thinner due to the compaction of the sediment, which reduces the growth of stem diameter. The stem diameter below the flower in medium treatment beds slightly increased with increasing sediment (Fig. 4). A slight decrease in stem diameter may be due to competition for nutrients among the treatment beds. Wang et al. (2005); Rongoei and Outa (2016), explain that in a non-self-thinning plant monoculture, many researchers have found that growth prohibition can occur when individuals compete for nutrients.

Stem density in the high treatment beds at the end of the experiment was less than the control beds and the other treatment beds (Fig. 6). This may be a physiological response to increased sediment. The stem density was highest in the control beds, which could lead to increase above-ground biomass. Plant growth may be inhibited as a result of competition (Wang et al. (2005); Wang et al. (2013). Many investigators have shown that a biomass distribution consisting of a few large plants and many small plants may develop when individuals compete for resources (Wang et al. 2013). In a previous study by Wang et al. (2013), dry mass production of *A. prostrates* decreased significantly in the higher density treatments. High density treatments indicated declines in height, and biomass of stems, leaves and roots in *A. prostrates* (Wang et al. 2005; Rongoei and Outa 2016). The decrease in stem density and growth parameters in the high sediment treatment compared to the control is likely due to sediment-related stress. Excess sediment may have reduced oxygen availability in the root zone or buried young shoots, limiting growth and establishment. Since all other environmental factors were maintained constant, competition among plants is unlikely to be a significant factor. Sediment accumulation around the root zone leads to soil compaction and reduces pore space, which restricts the diffusion of oxygen to the roots (Montenegro 2022). This condition, root hypoxia, can substantially impair root respiration and metabolic activity. *Cyperus papyrus*, while acclimated to marsh settings, requires an adequate oxygen supply for root function (Montenegro 2022). Anaerobic conditions prevail in oxygen-depleted sediments, causing the accumulation of hazardous chemicals such as sulphides and ethanol. These byproducts can affect root cell activity, decrease energy production through aerobic respiration, and eventually limit root development and vitality. The stress caused by reduced oxygen also affects the efficiency of water and nutrient transfer to the plant's aerial regions, compromising overall plant health (Li et al. 2020).

Many changes in papyrus in this experiment were typical of wetland plant responses to sediment loading, including increased biomass production, faster growth in plant height, stem diameter, and the occurrence of new shoots. The observations in this study made over a range of sediment availability in the environment suggest the existence of a compulsory balance between sediment and new shoot recruitment. Sediment depth and ecosystem characteristics influenced papyrus production, including growth rate, shoot recruitment, density, and mortality. Results were consistent with Webb et al. (2012), who showed that increased sediment depth can diminish shoot recruitment and density and increase shoot mortality.

Both wet and dry weights of each treatment of shoots and roots decreased with increasing sediment depth. The most pronounced effect of sediment depth on both wet and dry shoot and root weights occurred in the control beds in comparison to low, medium and high treatment beds, indicating a greater ability of plants in the control beds to compete for below ground resources. These results indicate that sediment depth could exacerbate the combined effects of climate change, water level fluctuations, and other environmental factors negatively impacting wetland ecosystems and supports sediment load control as a critical factor in managing wetland health. Alongside oxygen limitation, sediment stress can hinder the uptake of essential nutrients. The increased sediment load may alter the redox potential of the rhizosphere, affecting the chemical availability of nutrients such as nitrogen, phosphorus, and iron (Montenegro 2022). Moreover, hypoxic or anoxic conditions often lead to a decline in root membrane permeability and active transport functions, both of which are essential for efficient nutrient absorption. For instance, nitrogen uptake crucial for chlorophyll synthesis and protein formation can be severely reduced, leading to symptoms of chlorosis and stunted growth. Sediment may also physically obstruct fine root hairs, which are primarily responsible for nutrient acquisition, further diminishing uptake efficiency.

Our results agree well with the findings by Deb (2014), who studied the impacts of varied sediment depth on *Cyperus esculentus* L., *Aframomum angustifolium* (Sonn.) and *Phragmites australis* (Cav.) they demonstrated that sediment depth limitation was effective in increasing final plant weight. Root-shoot ratio decreased with increasing sediment depth in low (31 cm) and medium (35 cm) and high (40 cm) treatment beds. However, wet below-ground biomass in control beds (30 cm sediment) was 7.17 kg/2 m² compared to 3.80 kg/2 m² in the high treatment beds. A reduction in wet below-ground biomass of the plants along with increasing sediment depth signifies greater numbers of new shoots and higher plant density, leading to increased biomass accumulation. This was similar to other studies where roots were the major biomass component of wetland systems (Hoagland et al. 2011). Papyrus productivity depends on the depth of the sediment and the habitat conditions that enable higher rates of nutrient uptake (Edwards et al. 2003; Rongoei and Outa 2016). As papyrus is harvested and flooding with high sedimentation increases, provisioning and regulation services for papyrus diminish. There is a balance in the benefits and costs of sedimentation: although increased sediment depth from runoff can diminish overall productivity in papyrus, flood waters seasonally restore nutrients to the wetland so as to maintain continuous papyrus growth.

As sediment depth increases, the rate of growth decreases in both the below-ground and above-ground parts (Lovelock et al. 2007). An increase in root

to shoot ratio as noted in our control beds, may be attributed mainly to a reduction in shoot growth, as has been observed when water is limiting (Osório et al. 1998). During the experiment, some plants dried up and died, a visible indication that deepening sediment reduced root-shoot ratios. Subsurface physiological stress often manifests in aboveground impacts, notably impairing the process of photosynthesis. Limitations in nutrient uptake and water transport hinder chlorophyll synthesis, decrease stomatal conductance, and ultimately suppress the overall rate of photosynthesis. In *C. papyrus*, a species dependent on robust aerial biomass for key ecological functions such as carbon storage and habitat provision, diminished photosynthetic efficiency can lead to stunted shoot growth and lower biomass production. Additionally, sediment accumulation in aquatic environments may obstruct light penetration, thereby reducing the availability of light essential for photosynthesis in submerged or partially submerged plant structures (Li et al. 2020)

Beyond sediment depth, several factors were observed as possible causes of culm mortality in treatment beds, including climate, shade from taller plants, termites, and nutrient availability, however, these were not tested in our experiments. Increases in root-shoot ratio under increasing sediment depth may be attributable to decreased foliage area and intercepted solar radiation. This interpretation would align with Ren et al. (2016), who examined the effects of shading on the photosynthetic characteristics and mesophyll cell ultrastructure of macrophytes. When plants were stressed with high sediment levels and shade simultaneously, their growth was not only influenced by each of these two factors independently, but also by the effects that different sediment levels had on the resulting light intensity (Thouvenot et al. 2013). Sediment deposition reduces the range of daily temperature fluctuation and can provide an additional source of nutrients for plant growth. Stimulatory effects of shallow burial under waterlogged conditions have been reported in other wetland macrophytes (Pan et al. 2014a). Sediment burial not only promoted the seedling height growth and dry mass accumulation, increased the stem diameter and the number and length of branch, but also altered the dry mass allocation ratio of different parts. These impacts would be favorable for maintaining *S. salsa* populations and encouraging further growth in barren mudflat. Similar phenomena were also observed in some other species, for example seedlings emerging from a deeper location had higher seedling height, longer first internode or sub coleoptile internode, longer root system and increased dry mass accumulation (Mou and Sun 2011).

Although *C. papyrus* has some degree of adaptation to wetland and periodically waterlogged conditions such as aerenchyma tissue to facilitate internal oxygen transport, excessive sediment load can overwhelm these adaptations. Persistent sedimentation events may thus reduce the competitive ability of *C. papyrus*, allowing more tolerant species to dominate, ultimately altering community structure and ecosystem function.

Conclusion

In summary, sediment stress imposes a multifaceted physiological burden on *C. papyrus*, primarily through root hypoxia, impaired nutrient uptake, and reduced photosynthetic efficiency. These interconnected processes reasonably explain the observable declines in plant health and growth under

sediment-rich conditions and highlight the importance of managing sediment dynamics in wetland ecosystems to support the sustainability of this ecologically and economically important species.

Sediment level significantly influenced the morphological parameters investigated. Height, diameter, new shoots, above and below ground biomass were all impacted by sediment level in the treatments. These results demonstrate the importance of proper sediment management for the benefit of papyrus for maintaining healthy wetland ecosystems. Sediment depth in the constructed wetland significantly affected papyrus growth rates. Good growth performance was achieved in the control beds, while low growth rate, low culm density, and stunted growth of papyrus were observed in the high sediment treatment beds. Similarly, more shoots were developed in low and control treatment beds than medium and high treatment beds, demonstrating that increased sedimentation limits seedling recruitment and clonal dynamics. Control beds had higher rates of biomass accumulation as evidenced by the increase in new shoots and root weights compared to low, medium and high treatment beds. Generally, within this study sediment significantly affected height, diameter below flower, diameter above sediment and new shoot recruitment, but biomass was not significantly impacted by sediment depth. These results suggest that increases in wetland sediment load may lead to negative alterations in the species composition and functions of wetland ecosystems. A long-term, multi-year monitoring of *C. papyrus* populations is essential to evaluate their resilience and recovery patterns under sedimentation stress, providing insights into regrowth trends, biomass fluctuations, and critical ecological thresholds. Complementing this, a thorough analysis of sediment characteristics including particle size, organic matter, and nutrient content can inform more effective sediment management practices by clarifying how various sediment properties impact plant vitality and the broader functioning of aquatic ecosystems.

The knowledge that sediment loading has a negative impact on papyrus communities must be applied in order to have real-world value. Research should be conducted to examine various methods of sediment control in buffer zones around Lake Tana and the possible adjacent ecological impacts of sediment load limitation.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

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Use of AI

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Author contributions

Conceptualization: MM, KM. Data curation: KM. Formal analysis: KM. Funding acquisition: KM. Investigation: KM. Methodology: KM. Project administration: KM. Resources: KM. Software: KM. Supervision: AW, MM. Validation: KM, AW. Visualization: AW, MM. Writing - original draft: KM. Writing - review and editing: KM.

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Data availability

Data supporting this study are available from the corresponding author upon reasonable request.

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